CONSTELLATION SCHOOL ON

***X-RAYS FROM STAR FORMING REGIONS***

***Palermo, 18-22 May 2009***

constellation

# PALERMO
# 18-22 May 2009

# ABSTRACTS

## Monday – May 18

*X-ray Astronomy: a quick tour from the early days to the present and … beyond*

S. Sciortino
INAF - Osservatorio Astronomico di Palermo

I will briefly tour the development of X-ray Astronomy over the last 50 years, highlighting the technological developments and the space missions that have had, in my opinion, major impacts on the field, with specific emphasis on star forming region studies. I will briefly comment on the possible developments for the coming decade(s).

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*Thermal X-ray emission from forming stars*

Giovanni Peres
Universita` di Palermo

There will be a brief review of the main mechanisms by which forming stars emit thermal X-ray radiation. Main emphasis will be on coronal emission with some discussion on accretion emission and jets emission. Abundance effects and non equilibrium conditions will be shortly commented.

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*Stellar X-ray astronomy: The last 30 years*

Jurgen Schmitt
Hamburg Observatory

I will review the development of stellar X-ray astronomy of the last three decades. Starting from the development of solar coronal research I will illustrate how new instrumental developments established the field of stellar X-ray astronomy. The most important X-ray missions as well as the key players in the field will be presented. The main difference as well as similarities between stellar coronae and the solar corona will be discussed. The key findings of stellar X-ray astronomy will be highlighted.

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*X-Ray Telescopes*

Marco Barbera
Universita` di Palermo

In this talk I give a brief overview of the basic physical principles of X-Ray focusing and show the main characteristics of telescopes for X-ray Astronomy. Different geometries and construction techniques are compared with a particular emphasis on grazing incidence telescopes that are particularly efficient in the soft X-ray band. The performances of some X-ray telescopes used in past and current X-ray Astronomy missions are briefly described, together with some of the on-going developments for the construction of future X-ray Astronomy missions.

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*X-Ray Detectors*
Alfonso Collura
INAF - Osservatorio Astronomico di Palermo

X-ray detectors for astrophysical applications and their basic working principles are reviewed. The lecture starts from gas detectors and after an overview of the most used astronomical detectors, like microchannel plates and CCD's, ends with microcalorimeters, which represent the frontier of X-ray detection in astronomy.

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*Data Products of X-ray Observations*
Antonio Maggio
INAF - Osservatorio Astronomico di Palermo

This lesson deals with the content, format, and meaning of data related to X-ray observations with CCD detectors on board XMM-Newton and Chandra. In particular, I will give an overview of general properties of the data products generated by standard pipelines, i.e. those provided to the end user for the science analysis. A comparison with optical data will be employed to understand similarities and differences with observations performed with "traditional" telescopes

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## Tuesday - May 19

*X-rays from pre-main sequence stars*
Eric Feigelson
Penn State University

Over the past 30 years, imaging X-ray observations of nearby star forming regions have established that normal solar-type stars exhibit their highest levels of magnetic activity during their pre-main sequence phases. Above 1 keV, the emission is dominated by magnetic reconnection flares similar to, but much more powerful and frequent than, contemporary solar flares. Some flare properties (e.g. plasma abundances) are similar to those of older stars, while others are not (e.g. scaling with mass not rotation). X-ray emission from accretion shocks, collimated jets, and Interactions between magnetic loops and the accretion disk may be present in younger systems. Finally, we present empirical relationships describing the decay of X-ray activity over a star's lifetime from 0.1 Myr to 10 Gyr.

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*X-rays and stellar populations*
Francesco Damiani
INAF - Osservatorio Astronomico di Palermo

I will describe how X-ray observations of star formation regions have profoundly changed our perspective on their global populations. Starting from the Einstein Observatory results on the relatively nearby Taurus-Auriga cluster, it was soon realized that in practically all star-forming clusters optical and IR observations alone are likely to miss an often substantial, or even dominant, fraction of cluster members with little optical/IR peculiarities, which instead stand out clearly in X-

ray images. I will sketch examples of such X-ray selected populations in a number of clusters, as studied with current-generation X-ray observatories, and how such an improved star census impacts dramatically on our knowledge of global cluster properties, such as the IMF shape, cluster formation history (and sometimes sequence), cluster morphology, mass segregation, circumstellar disk frequency and evolution.

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*Magnetic properties of young stars*

Moira Jardine
University of St Andrews

Throughout the early stages of a star's lifetime, from the pre-main sequencephase through to the main-sequence, the nature of a star's magnetic field has a significant influence both on the star itself and also on its environment. This magnetic field not only powers the stellar coronal X-ray emission, but may also mediate the interaction between the star and its surrounding protoplanetary disk. The exchange of torques between the star and the disk appears to determine the rotational evolution of the star, while the accretion of material from the disk onto the star is governed by the stellar magnetic field. Once the disk has dispersed, the loss of angular momentum in a hot, magnetically-channeled wind continues to spin the star down as it evolves onto the main sequence.
In this talk I will review the present state of our understanding of these magnetic fields and their role in determining the behaviour of young stars.

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*X-rays, Protoplanetary Disks and Planet Formation*

Eric Feigelson
Penn State University

The enhanced X-ray emission from magnetic activity of pre-main sequence stars is likely to illuminate protoplanetary disks, heating and ionizing the outer layers. We outline several lines of evidence from X-ray and infrared spectroscopy that support this illumination. Hard X-rays should penetrate deeply into the disk, possibly into the mid-plane, inducing MHD turbulence via the magnetic rotational instability. Such turbulence should have profound effects on the coagulation of dust into planetesimals, and on the inward migration of bodies. Energetic particles from magnetic reconnection flares may also produce radioactive isotopes in solids by spallation, as found in ancient meteoritic components.

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*The interaction of stellar high energy radiation with hydrogen rich planetary atmospheres*

Cesare Cecchi Pestellini
INAF - Osservatorio Astronomico di Cagliari

The evolution of planetary atmospheres can only be understood within the context of the evolving stellar radiation environment. From the study of stellar proxies for the Sun it appears that young solar type stars emit high energy photons at a level three to four orders of magnitude higher than the present-day Sun, both during the pre-main sequence phase when the emission is dominated by intense daily or weekly flares, and during the first phases of the main sequence. Such an intense illumination must have affected circumstellar disk and the process of planetary formation during the pre main-sequence phase, and, subsequently when the star reached the main sequence, the evolution

of planetary atmospheres. Indeed, high energy radiation impinging on a planetary atmosphere is a crucial ingredient that determines the crossover between stability and instability of planets orbiting solar-type stars.
In this talk, I will discuss the interaction of EUV radiation and X-rays with giant planet atmospheres. The processes described occur frequently in many astrophysical environments. A unique feature of photon irradiation with energies beyond the Lyman continuum is that all the relevant processes are dominated by secondary ionizations generated by primary photoelectrons. This is a consequence of the large primary photoelectron energies. Indeed, the secondary processes are far more important than the corresponding ionization, excitation, and dissociation events caused directly by high-energy photons. Radiative transfer of incident stellar flux determines the local radiation density, that in turn controls the physics and the chemistry of the nebular phase.

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## Wednesday - May 20

*X-ray image analysis*

Francesco Damiani
INAF - Osservatorio Astronomico di Palermo

I will present techniques for analysis of astronomical X-ray images. I will recall the most important differences with respect to imaging data in other wavebands, for instance: ability to select images in selected time- or energy ranges; apply time- and energy-filtering of background to maximize signal-to-noise ratios; problems of mosaiced images with dithering; spatially variable PSF/resolution; photon pile-up; particle detection and afterglows.
I will trace shortly a historical path of progress, from Einstein IPC to Chandra HRC/ACIS images, leading to very low-background high-resolution images, and permitting deep imaging surveys.
I will present in some details some widely used source detection techniques, such as local (cell) and wavelet detect, with their strengths and weaknesses, e.g. regarding: multiscale sources; detector edges and gaps; multi-scale background evaluation; threshold calibrations and confidence levels for source existence; count-rate and size estimation; errors; PSF corrections; artifacts for bright sources.

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*Spectral and variability analysis*

Antonio Maggio
INAF - Osservatorio Astronomico di Palermo

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*Epsilon Indi Ba, Bb: dynamical masses for the nearest brown dwarf binary*

Catia Cardoso
Exeter University

We present new preliminary astrometric results for the closest known brown dwarf binary to Earth, Epsilon Indi Ba, Bb at a distance of 3.6224 pc. The relative orbital motion of the brown dwarfs (spectral types T1 and T6) has been monitored since June 2004 with the VLT NACO near-IR adaptive optics system. With data for more than half the orbit now, we obtain an accurate total dynamical system mass (<1%), considerably in excess of earlier determinations based on evolutionary models. We have also been monitoring the absolute astrometric motion of the system since August 2005 against a network of field stars using the VLT FORS2 optical imager with the aim of determining the individual masses. Our current orbit solution predicts periastron passage in early 2010, and shortly thereafter, we should be able to determine the absolute masses to better than 5% in a model independent way.

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*Probing the low-mass end of the IMF in the Rho Ophiuchus Molecular Cloud*

Catarina Alves de Oliveira*, Jerome Bouvier, Estelle Moraux
*LAOG – Grenoble

The characterization of young stellar populations in star forming regions down to the planetary mass regime is a fundamental step towards the understanding of the physics behind their formation. We present the preliminary results of a major observational study of the low mass population of the 1 Myr old Rho Ophiuchus Molecular Cloud. Candidate brown dwarfs and isolated planetary mass objects have been identified using the deepest near-IR imaging survey of the entire region (WIRCAM/CFHT). A near-IR spectroscopic follow-up of these candidates is under way using several facilities (TNG, GTC, NTT, ISAAC), which will allow for an estimation of their spectral types and masses, and ultimately, to construct the low-mass end of the IMF for this star forming region.

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*Multi-wavelength diagnostics of accretion in an X-ray selected sample of CTTSs.*

Rachel Curran*, Costanza Argiroffi, Germano Sacco, Salvatore Orlando, Fabio Reale, Giovanni Peres, Antonio Maggio
*INAF – Osservatorio Astronomico di Palermo

The majority of CTTSs observed to date with high spectral resolution X-ray spectrocopy reveal soft X-ray emission (E < 0.7 KeV) which originates from cool (1-5 MK), high density (n ~ 10^11 - 10^13 /cm^3) plasma. Current theory suggests this arises from mass accretion, however mass accretion rates calculated from X-ray data are consistently underestimated when compared to mass accretion rates derived from UV/optical data. We test the theory that this soft X-ray emission arises from mass accretion by analysing optical, NIR and X-ray data for an X-ray selected sample of CTTSs. We calculate mass accretion rates from H-alpha, HeI, OI and CaII emission lines, along with the X-ray data. Comparisons are made between the mass accretion rates from optical/NIR data and X-ray data to understand the underestimation of the X-ray derived mass accretion rates.

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*Automated spectral classification of pre-main sequence stars in NGC 6530*

Ella Hopewell
INAF – Osservatorio Astronomico di Palermo

NGC 6530 is a rich open cluster located about 1250pc away and has been the subject of an ongoing project to investigate its stellar population. I will report on my efforts to use automated spectral typing methods to classify ~100 stars observed using VIMOS. Assigning spectral types to the stars in the sample is important in determining physical stellar parameters such as mass, luminosity and temperature. I will present an overview of the spectral typing processes used and the results obtained so far.

*Observations and modeling of X-ray emission from protostellar jets*

Sara Bonito
INAF – Osservatorio Astronomico di Palermo

X-ray emission from shocks in protostellar jets has been discovered by both XMM and Chandra, and it is now considered as a possibly general feature of such objects.
Prompted by these observations, we aim at explaining the physical mechanism leading to X-ray emission from protostellar jets by developing a hydrodynamic numerical model of the interaction between a supersonic jet and the ambient medium. We found that the shock heating mechanism explains the X-ray emission detected in protostellar jets in a natural way (Bonito et al. 2004, 2007) since protostellar jets ram supersonically into the ambient medium and shocks form at the interaction front between the jet and the medium, possibly heating the plasma at million degrees, thus leading to X-ray emission.
As for the data analysis, we studied the X-ray source variability detected with Chandra for the HH 154 jet, the nearest jet from which X-ray emission has been detected and the only protostellar jet whose X-ray source's proper motion has been measured so far. One of the most interesting result of these data (Favata, Bonito et al. 2006) is that the X-ray source shows a complex morphology, including a shock moving away from the parent star with a speed consistent with our model's results.
Albeit the moving shock model reproduces many of the physical properties of the detected X-ray source, it appears that a more complex scenario of the star, shock and surrounding medium may be required. Here we present our preliminary results of the hydrodynamic numerical model of a jet ejected with a random initial velocity, which causes self-interactions between blobs ejected at different epochs and with different speed, and a multi-structures morphology as that observed in the HH 154 X-ray source. The model here discussed can be extended to other jets besides HH 154, thus addressing how common this emission is and how long it persists along the protostellar evolution.

*Modeling of the accretion shock on CTTSs and its X-ray emission*

Germano Sacco
INAF – Osservatorio Astronomico di Palermo

High resolution (R~600) X-ray observations of CTTSs demonstrate the presence of plasma at temperature $T=2\text{-}3*10^6$ K and electron number density $n\_e\sim10^{11}\text{-}10^{13}cm^{-3}$. Physical properties of plasma (temperature and density) suggest that it is heated by the accretion shock close to the stellar surface. We address this issue by HD and MHD numerical modelling of the interaction between the accretion flow and the stellar chromosphere. Our models include the gravity, the radiative losses from an optical thin plasma and the thermal conduction. Here, we present the results of both 1D HD and 2D MHD simulations and the comparison between the results of simulations and an high resolution X-ray spectrum of a CTTSs.

## Thursday – May 21

*X-rays from massive stars*

Thierry Montmerle
Laboratoire d'Astrophysique de l'Observatoire de Grenoble

Since the seminal paper published in 1981 by R. Pallavicini et al. based on Einstein observations, we know that massive, OB stars are X- ray emitters (as are WR stars), albeit much less efficiently (in terms of Lx/Lbol) than late-type stars. Surveys by ROSAT have confirmed these conclusions, although the case of A stars has remained ambiguous for a long time. The most popular mechanism to explain the X-ray emission from OB stars is from shocks in their strong, radiatively unstable winds. More recently, however, increasing evidence has been found that OB stars, contrary to conventional wisdom, could harbor magnetic fields that play a decisive role in channeling their winds and modifying their X-ray properties. I will mainly review this last aspect, including follow-up observational quests for magnetic fields in X-ray emitting O, B, and A stars.

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*X-ray Insights into Young Stellar Clusters*

Eric Feigelson
Penn State University

Most stars form in rich stellar clusters dominated by OB stars in giant molecular cloud complexes. The Chandra X-ray Observatory has now surveyed most of the rich stellar clusters in star forming regions within d~3 kpc. A typical X-ray image reveals hundreds of pre-main sequence stars in the mass range 0.3-3 Mo, and dozens of higher mass stars. In contrast to infrared surveys, the X-ray samples suffer little contamination by older Galactic field stars and nebular HII region nebular emission. A number of new findings are summarized: Initial Mass Functions inferred from X-ray luminosity functions; smooth and clumpy spatial structures suggesting different dynamical origins; triggered star formation on the periphery of HII regions; and the fate of OB winds. Results from M 17, Cep OB3, W 3, and the Rosette and Carina Nebulae are highlighted

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*Shock physics and X-ray diagnostics in massive star-forming regions*

Thierry Montmerle
Laboratoire d'Astrophysique de l'Observatoire de Grenoble

Massive stars not only emit X-rays by themselves, close to their surface, but they interact strongly with their surrounding medium, creating pc-scale diffuse X-ray emission. The corresponding plasma originates in high-speed shock waves, either from their strong winds (standing shocks during most of the stellar lifetime), or from supernova explosions (temporary, fast expanding shocks), or both. Depending on the nature of the shocks, and on the confinement properties of the cold, molecular material in their vicinity, X-ray "bubbles" and/or "champagne flows" can be created. This hot gas can be contaminated by nucleosynthetic material and have "anomalous" abundances. Also, over time, successive generations of exploding massive stars can create "superbubbles", or "fountains" of hot gas leaving the galaxy.

In addition to describing the relevant X-ray processes, I will briefly discuss two consequences of supernova explosions in star-forming regions: (i) the TeV gamma-ray emission recently observed in some of these regions, and (ii) clues to the early history of the solar system as deduced from the past presence of 60Fe in meteorites.

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*Molecular outflows towards O-type young stellar objects*

Ana Lopez Sepulcre
INAF – Osservatorio Astrofisico di Arcetri

The formation of massive stars is not well-understood and requires detailed observational studies in order to discriminate between the different proposed star formation models. In this context, we have searched for massive molecular outflows in a sample of high-mass star forming regions, and we have characterised both the outflow properties and those of their associated molecular clumps. The sample under study has been selected so as to favour the earliest evolutionary phases of star formation, and is composed largely of more luminous objects (possibly O-type stars) than previous surveys, thus complementing analogous studies performed by other authors by adding the highest luminosity sources. Each object in our sample has been mapped in the 13CO(2-1) and C18O(2-1) lines at 1.3 mm with the IRAM-30m telescope at Pico Veleta (Spain). Our results indicate that molecular outflows are as common in massive star forming regions as in low-mass star forming regions, and that the outflow-related parameters (mass loss rate, mechanical force, etc) increase with mass and luminosity of the clumps. This, added to the detection of a few tentative large-scale rotating structures suggests that high-mass stars may generally form via accretion, as low-mass stars.

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*Massive stars in embedded HII regions*

Arabela de la Nuez Cruz
Potsdam

Even though massive stars are important in the Universe, it is still not clear how they are formed. There are several origin models but more observations and studies are needed to solve the problem. In our work we are studying Bracket gamma images of very young star forming regions (Cygnus and Carina). We want to find new embedded HII regions and their exciting OB stars and explore their properties (e.g. binarity and clustering) at the early stages of their life.

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*Magnetism in Herbig Ae/Be stars*

Evelyne Alecian
Observatoire de Meudon

One of the most challenges, today, in stellar physics is to understand the origin of the magnetic fields of stars, and in particular among the intermediate mass A/B stars. Our favoured hypothesis is the fossil theory, implying that the magnetic fields observed among the main sequence A/B stars are relics from the magnetic fields present in the parental molecular clouds, or generated very early during the stellar formation. This theory implies also that, once the star is formed, their magnetic fields survive to the various phases of stellar evolution without regeneration. However, until recently, we were strongly missing information about the magnetism in the pre-main sequence stars of intermediate mass, that we mostly found among the Herbig Ae/Be stars. In order to test the fossil field theory, we performed a high-resolution spectropolarimetric survey of the Herbig Ae/Be stars using the new generation instrument ESPaDOnS, installed at the Canada-France-Hawaii telescope. In this talk I will present our results as well as the implications on the X-rays emissions observed in some of these very young stars.

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**Friday - May 22**

*Open questions and the future*
Fabio Favata
ESA Headquarters